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Hydrogen bond patterns in 3-carboxypiperidinium semi-oxalate monohydrate

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Resumen

El cristal multicomponente $C_6H_{12}NO_2^+C_2HO_4^-\cdot H_2O$, o $NIPE^+$:$OXAL^-$:HYDR, es un ensamblaje iónico asistido por enlaces de hidrógeno. El aminoácido $NIPE^+$ es un catión, una molécula $OXAL^-$ es un ión semi-oxalato, y la molécula de agua actúa como solvente. Las moléculas están conectadas por enlaces de hidrógeno del tipo O--H···O y N--H···O, formando cadenas lineales··semi-oxalato··semi-oxalato··extendidas a lo largo de *a* y descritas por el grafo C(5). Estas cadenas interactúan con el grupo NH_2^+ del $NIPE^+$ construyendo un empaquetamiento cristalino bidimensional descrito por los grafos $R^2_1(5)$, $R^2_4(8)$ y $R^5_5(19)$, con capas corrugadas que corren en un plano (001), y separadas por interacciones hidrofóbicas en *c/2*. Se presenta el análisis de las estructuras de los componentes individuales y de la red de enlaces de hidrógeno de la estructura cristalina.

Palabras clave: estructura cristalina por difracción de rayos-X; enlaces de hidrógeno; cristales multi-componente

Abstract

The crystal structure of compound $C_6H_{12}NO_2^+\cdot C_2HO_4^-\cdot H_2O$, or $NIPE^+\cdot OXAL^-\cdot HYDR$, is an ionic ensemble assisted by hydrogen bonds established between $NIPE^+$ cations, $OXAL^-$ semi-oxalate anions and water molecules. The molecules are connected by O--H···O and N--H···O hydrogen bonds, forming linear ···semi-oxalate···semi-oxalate··· chains extending along the *a* axis and described by the graph-set motif C(5). These chains interact with the NH_2^+ group of $NIPE^+$ and the water molecules building a two-dimensional crystal packing of rings described by graph-set $R^2_1(5)$, $R^2_4(8)$ and $R^5_5(19)$, with corrugated layers running parallel to the (001) plane, and separated by hydrophobic interactions at *c/2*. Analyzes of the structures of the individual components and the hydrogen-bond network of the crystal structure are given.

Keywords: Single-crystal X-ray diffraction; Hydrogen bonding; multi-component crystal

Introduction

Amino acids with oxalic acid form interesting ionic ensembles assisted by hydrogen bonds[1,2], in which the oxalic acid exists as semi-oxalate[3,4] or oxalate[5], or even with both forms cohabitating in the same structure[6]. In these ensembles, mostly formed with α-amino acids, the acidic proton goes to the amino acid acting as the counter-ion[7]. In addition to the ionic interactions, there are strong hydrogen bonds making these structures very stable chemical systems. For example, in the multi-component crystal reported in the Cambridge Structural Database (CSD, Version 5.33, Aug. 2012)[8] L-leucinium oxalate[9], semi-oxalate ions, strongly linked with each other by hydrogen bonds of the type O-H···O, form linear and planar chains described by graph-set motif C(5). These chains link to L-leucinium by means of bifurcated hydrogen bonds of the type N--H···O and O--H···O forming rings described by graph-set motif $R^2_1(5)$. These types of supra-molecular structures are also seen in L-lysine dioxalate[10]; DL-alaninium oxalate[4]; L-alaninium oxalate[11]; L-cysteinium semioxalate[12] and β-alaninium oxalate[13]. On the other hand, glycine oxalate[3] and DL-alaninium semioxalate monohydrate[14] display similar motifs although with non-planar ···semi-oxalate···semi-oxalate··· chains.

In recent years, we have been interested in a systematic study of cyclic amino acids directed to understanding the influence on the observed crystal packing of the position of the amino group inside the cycloalkane ring such as in 2-piperidine carboxylic acid[15], 3-piperidine carboxylic acid and 4-piperidine carboxylic acid[16-19] and outside the cycloalkane ring such as in 4-aminoclohexane carboxylic acid[20,21].

In this work, we used 3-carboxypiperidinic acid (nipecotic acid), NIPE, an inhibitor in the synthesis of γ-aminobutyric acid and reported as a zwitterion[22-24], mixed with oxalic acid, OXAL, a very strong acid reported in the solid state as catamers (α-form) or dimers (β-form)[25], to obtain the multicomponent crystal 1:1:1 $NIPE^{+}$:$OXAL^{-}$:HYDR, scheme 1.

Experimental

Synthesis

The multi-component crystal $NIPE^{+}$·$OXAL^{-}$·HYDR was prepared by mixing equimolar quantities of nipecotic acid (0.0462g, Aldrich 98%) with commercial grade oxalic acid dehydrated (0.0671 g, Aldrich 99.8%) dissolved in sufficient water (scheme 1). The mixture was placed in a reflux system for three hours at constant temperature of ~343K. Colorless crystals of suitable size for X-ray diffraction experiments were obtained by the slow evaporation during two months of the reflux solution. Melting point: 498.4-500.6K.

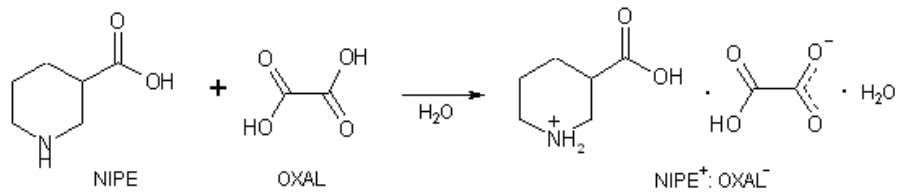
FT-IR analysis

FT-IR, 3420 cm^{-1}[t, OH (acid group)], 3240 cm^{-1} [t, OH (crystallization water)], 1728 cm^{-1} [t, C=O (acid group from OXAL and NIPE)], 2602 cm^{-1} [t, N−H (amino group of NIPE)].

X-ray data collection and structure determination

A colorless rectangular crystal (0.4, 0.2, 0.1mm) was used for data collection. Diffraction data were collected at 298(2)K by ω-scan technique on a Rigaku AFC7S Mercury diffractometer[26] equipped with graphite-mono-chromatized MoK_{α} radiation (λ = 0.71073Å). The data were corrected for Lorentz-polarization and absorption effects[27]. The structure was solved by direct methods using the SIR08 program[28] and refined by a full-matrix least-squares calculation on F^2 using SHELXL[29]. All hydrogen atoms were placed in calculated positions and refined using the riding model with C−H = 0.97Å, N−H = 0.90Å and O−H= 0.82Å and with their isotropic temperature factors set to 1.2 times those of their riding C, N and O atoms. The hydrogen atoms of the crystallization water molecule were localized in a difference Fourier map and refined isotropically in an independent manner. Table 1 displays the crystallographic data and the structure refinement parameters. All figures were performed using the Diamond software[30].

Crystallographic data for the structure reported here have been deposited with the Cambridge Crystallographic Data Centre (Deposition No. CCDC-892976). The data can be obtained free of charge via http://www.ccdc.cam.ac.uk/products/csd/request/ (or from the CCDC, 12 Union Road, Cambridge CB2 1EZ, UK; Fax: +44 1223 336033; e-mail: deposit@ccdc.cam. ac.uk).



Scheme 1: Synthesis of $NIPE^{+}$:$OXAL^{-}$:HYDR.

Results and Discussion

The multi-component crystal $NIPE^{+}$·$OXAL^{-}$·HYDR crystallizes as a monohydrate. The asymmetric unit (see figure 1) consists of a $NIPE^{+}$ ion with a positive charge resting over the nitrogen atom N1, an $OXAL^{-}$ molecule as a semi-oxalate ion and a solvent water molecule.

In $NIPE^{+}$, the piperidinium ring adopts the chair conformation[31], and the COOH group has C1-O1 and C1-O2 distances of 1.292(4)Å and 1.204(4)Å, respectively. The semi-oxalate $OXAL^{-}$ has a planar conformation, with torsion angles O3-C7-C8-O5 and O4-C7-C8-O6 of -1,7(4)º and -1,1(4), respectively. A search in the CSD[8] (with R-factors less than 0.05) showed 94 structures with the semi-oxalate almost planar with torsion angles close to 0,0º, 55 structures in the range (2-10)º, 43 in the range (10-50)º, 13 in the range (50-90)º and only one structure in the bended conformation with torsion angle near 90º.

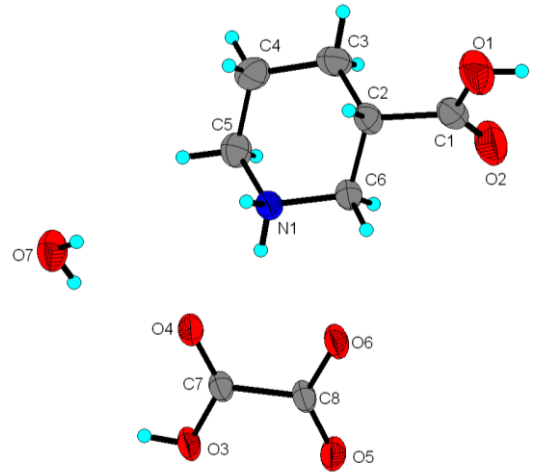


Fig. 1: Asymmetric unit of $NIPE^{+}$·$OXAL^{-}$·HYDR, showing the atom-labeling scheme. Displacement ellipsoids are drawn at the 35% probability level

Table 1: Crystal data, data collection and structure refinement

Chemical formula	$C_6H_{12}NO_2.C_2HO_4.H_2O$
Formula weight	237.21
Crystal system	Orthorhombic
Space group	Pbca
a(Å)	11.184(4)
b(Å)	11.895(4)
c(Å)	16.781(6)
V(Å^3)	2232.4(1)
Z	8
d_x (g cm^{-3})	1.412
F(000)	1008
μ(mm^{-1})	0.125
θ range (°)	2.4-27.6
hkl range	$-13 \le h \le 14$
	$-13 \le k \le 13$
	$-21 \le l \le 21$
Reflections	
Collected	23407
Unique (R_{int})	2318 (0.053)
With I > 2σ(I)	1634
Refinement method	Full-matrix least-squares on F^2
Number of parameters	153
R(F^2) [I > 2σ(I)]	0.071
*w*R(F^2) [I > 2σ(I)]	0.180
Goodness of fit on F^2	1.16
Max/min Δρ (e Å^{-3})	0.36/-0.22

Table 2 shows the geometry of the hydrogen bonds in the multi-component crystal $NIPE^+$·$OXAL^-$·HYDR. The $OXAL^-$ molecules interact with each other by means of hydrogen bonds of the type O3--H3···O6^{iii}, forming linear ···semi-oxalate···semi-oxalate··· chains extending along the *a* axis which can be described by the graph-set motif C(5)[32,33] (see figure 2). The torsion angle formed by two adjacent semi-oxalate molecules and linked by the abovementioned hydrogen bond is 71.10º describing a coiled chain. A search in the CSD[8] showed no preference in the conformation of these types of chains, with reported torsion angles varying in the range 0º (planar) to 90º (coiled).

$NIPE^+$·$OXAL^-$·HYDR packs in a two-dimensional structure, with corrugated layers running parallel to (001) plane, with the layers being separated by hydrophobic interactions at *c/2* (see figure 3). Figure 2 also shows the various hydrogen bonds involved in the construction of one layer; the coiled $OXAL^-$ chain, with the graph-set motif C(5), interacts with the NH_2^+ group of $NIPE^+$ forming two bifurcated hydrogen bonds, H1A interacting with O3 and O5, and H1B interacting with O4 and O6 of the $OXAL^-$ by means of hydrogen bonds of the type N1--H1A···O3^i, N1--H1A···O5^i and N1--H1B···O4^{ii}, N1--H1B···O6^{ii}, respectively. These set of hydrogen bonds form two rings described by graph $R^2_1(5)$, also observed in compounds ammonium hydrogen oxalate[34] and 4-hydroxyiminomethyl-pyridine oxalate[35]. $OXAL^-$ interacts with the water molecule through O7--H7A···O4^{iv} and O7--H7B···O5^{iii}, forming by combination with N1--H1A···O5^i and N1--H1B···O4^{ii} H-bonds a $R^2_4(8)$ ring also observed in ammonium oxalate[36]. Finally, the HOOC- group of the amino acid $NIPE^+$ forms a hydrogen bond with the water molecule through O1--H1···O7. An ample view of the packing shows that along the *b* axis, a chain of edge-fused rings, $R^2_1(5)$-$R^2_4(8)$-$R^2_1(5)$, illustrates how the oxalate links to water and to the amino acid.

This chain and its symmetry equivalent one (by lattice translation along the *a* axis) are connected via $OXAL^-$, $NIPE^+$ and water molecules to form $R^5_5(19)$ ring.

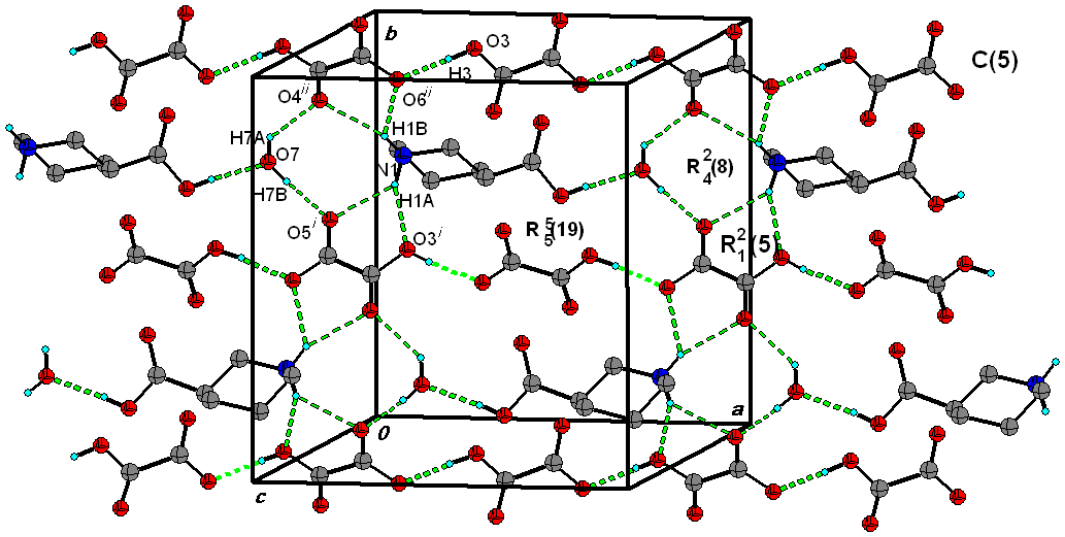


Fig. 2: Partial view of one of the corrugated layers running parallel to (001) plane. H atoms not involved in hydrogen bonding have been omitted for clarity.

Table 2:Hydrogen bonds geometry (Å, º)

D--H···A	D--H	H···A	D···A	D--H···A
O1--H1···O7	0.82	1.84	2.66(3)	175
N1--H1A···O3 (i)	0.90	2.20	3.02(3)	151
N1--H1A···O5 (i)	0.90	2.15	2.84(3)	133
N1--H1B···O4 (ii)	0.90	2.16	2.98(3)	151
N1--H1B···O6 (ii)	0.90	2.24	2.92(3)	132
O3--H3···O6 (iii)	0.82	1.69	2.46(3)	157
O7--H7A···O4(iv)	0.82(6)	2.27(6)	2.93(4)	137(5)
O7--H7B···O5(iii)	0.89(6)	1.91(6)	2.796(4)	176(6)

Symmetry codes: (i) 1/2+x,y,1/2-z, (ii)1/2-x,1/2+y,z (iii) -1/2+x,y,1/2-z (iv)-1/2-x,1/2+y,z.

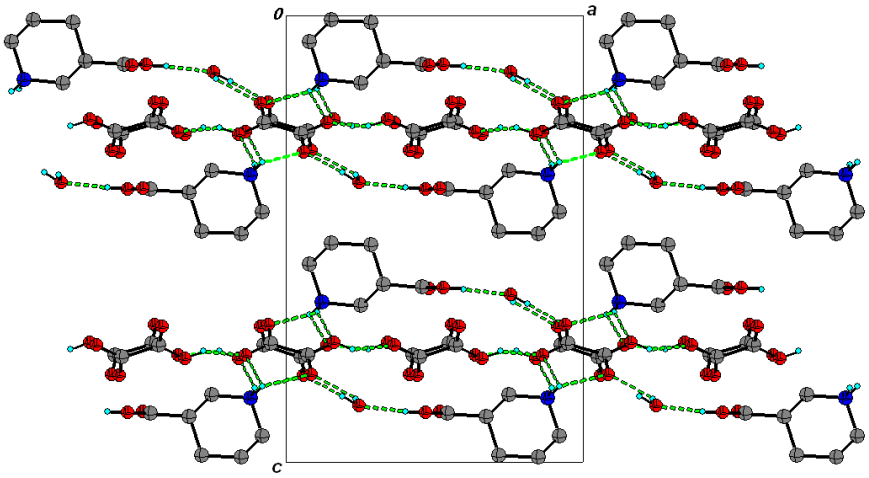


Fig. 3: Partial view of the two-dimensional crystal packing of $NIPE^{+}\cdot OXAL^{-}\cdot HYDR$ in the *ac* plane, showing the corrugated layers separated by hydrophobic interactions at *c/2*. H atoms not involved in hydrogen bonding have been omitted for clarity.

Aknowledegments

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